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Measuring access to primary medical care: some examples of the use of geographical information systems

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This paper explores the potential for geographical information system technology in defining some variables influencing the use of primary care medical services. Eighteen general practices in Scotland contributed to a study examining the accessibility of their services and their patients' use of the local Accident and Emergency Department. Geo-referencing of information was carried out through analysis of postcode data relating to practices and patients. This information was analyzed using ARC/INFO GIS software in conjunction with the ORACLE relational database and 1991 census information. The results demonstrate that GIS technology has an important role in defining and analyzing the use of health services by the population. © 1998 Elsevier Science Ltd. All rights reserved.

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Introduction

The provision of Health Care in the United Kingdom has undergone many changes in recent years, the most recent substantial change being the separation of purchaser and provider functions and the creation of the internal market for health in April 1991. Increased importance has been placed on identifying present and future health needs of the population as a more market based approach to health care has been adopted. Commissioning and purchasing authorities require a clear understanding of the health needs and behavior of the population in order that they may procure the most appropriate services. Previous studies have examined the relationship of patients using both primary (Knox, 1979; Joseph and Bantock, 1982) and secondary (Joseph and Phillips, 1984) care services and emphasis has been placed on those factors which influence patients accessibility to health services. Accessibility can be judged in both socio-organizational and geographical terms (Joseph and Phillips, 1984) with patterns of utilization of

health services generally being viewed as a manifestation of accessibility (Hayes *et al.*, 1990; Phillips, 1979). Utilization of health services has been found to vary with such factors as distance (Ingram *et al.*, 1978) and the age, sex and income of patients (Joseph and Poyner, 1982; Fiedler, 1981).

There is an inherently spatial component to many of these information needs which should be considered when analyzing health needs and patient behavior. The significance of this remains to be fully recognized, at least in the United Kingdom. Not only must attitudes and organizational structures change to meet with the present information requirements, but more powerful analytical tools must also be utilized. Geographical information systems (GIS), with their powerful database and display functions allow for the integration of data from numerous sources and the performance of detailed analysis taking into consideration the location of the variables in question – whether patients, services, or social and economic variables which might be of relevance. As such, GIS lends itself well to health related studies. To date however, this technology

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has been explored in only a limited way in the health arena (Lovett, 1992) although this present journal has recently been published and is devoted to examining the issues of "health and place".

Early applications of GIS in the health field focused on epidemiological issues (Glass, 1991; Nicol, 1991; Matthews, 1991; Dunn, 1992) — the "distribution and determinants of health and disease in groups" (Sackett *et al.*, 1991); more recently GIS has been applied to the planning and management of health care services — applications ranging from the creation of health profiles (Curtis, 1989; Kivell and Mason, 1992; Bloemberg *et al.*, 1992) to the location of service centers (Morgan, 1990; Clarke, 1992; Dowie *et al.*, 1995) and route planning.

In order to explore the potential benefits of GIS technology in the health care field, a detailed case study was performed employing GIS software and methods. The study, investigating issues of accessibility of primary care in West Lothian, Scotland, was completed as part of a larger project (previously reported (Campbell, 1994)) examining the determinants of accessibility of primary care medical services provided either by the general practitioner or the accident and emergency department (AED). Knox (1978) has demonstrated the increasing use of accident and emergency services by patients who have limited access to general practitioner services; in these situations accident and emergency departments may be viewed as providing a surrogate for general practitioner services.

Method

All 26 general medical practices in West Lothian, Scotland (*Figure 1*) were invited to participate in a study examining the relationship between the operation of general practitioner appointment systems and patients' use of accident and emergency services. All agreed to provide information regarding the practice size and practice postcode. Eighteen also agreed to contribute to a larger study (Campbell, 1994) examining the performance of any appointment systems they might operate. As part of this study, all patients attending their general practitioner during a one week period were invited to complete a questionnaire. Information was obtained on the patient's home postcode, their means of travel to the practice, and their perceptions of the accessibility of local medical services. Responses were obtained using a five point scale for estimated travel time (<15, 15–30, 30–45, 45–60 and >60 mins) and four point scale for estimated travel distance (<1, 1–2, 2–5 and >5 miles). Information regarding postcodes and source of referral was also obtained from data capture of the computerized

medical record of all patients attending the local Accident and Emergency department during a concurrent eight week period.

Postcode data obtained for patients and practices was geo-referenced using the POSTZON programme (Colchester:ESRC Data Archive, 1988) to assign five digit national grid coordinates to each record. Geo-referencing of postcode data permitted mapping of this information on digital map files of roads and geographic boundaries obtained from the University of Edinburgh Department of Geography. The majority of the attribute data was held within the ORACLE relational database management system which was linked to the GIS software ARC/INFO.

A variety of GIS techniques were selected for analysis of the data. These ranged from simple querying and display to more complicated techniques designed to evaluate such issues as (i) straight line and network distances (i.e. distances which take into consideration the road network over which people must travel) between the patients home and the service center (ii) the effect of distance on the utilization of services, (iii) the overall accessibility of those services, and (iv) patterns of patients' utilization and perception of service accessibility.

Network distances were calculated using the network functions within ARC/INFO and the ability of the software to assign each patient to their closest road segment. The effect of distance on the use of AED services was investigated by using buffer and convex hull techniques¹ to create straight line and network distance rings at consistent intervals centered on the AED. Geo-referencing of postcodes permitted allocation of patients to one of five buffer zones (0–2, 2–4, 4–6, 6–8 and 8–10 km) depending on their straight line or network distances (calculated separately) from the accident and emergency department. Spatial overlays were performed in order to calculate both the number of patients and the total number of people (derived from 1991 census information) within each ring, thus allowing comparison between the rings of the percentage of the population self referring to AED in the eight week study period.

Integration with 1991 postcode level census data permitted calculation of Jarman's underprivileged area scores (UPA) (Jarman, 1983) for the 20 postcode sectors of West Lothian, and provided information on car and home ownership. This measure was originally developed as an attempt to predict geographical areas with socioeconomic characteristics associated with increased general practitioner workload. The UPA score was examined as one variable potentially explaining the use of accident and emergency services.

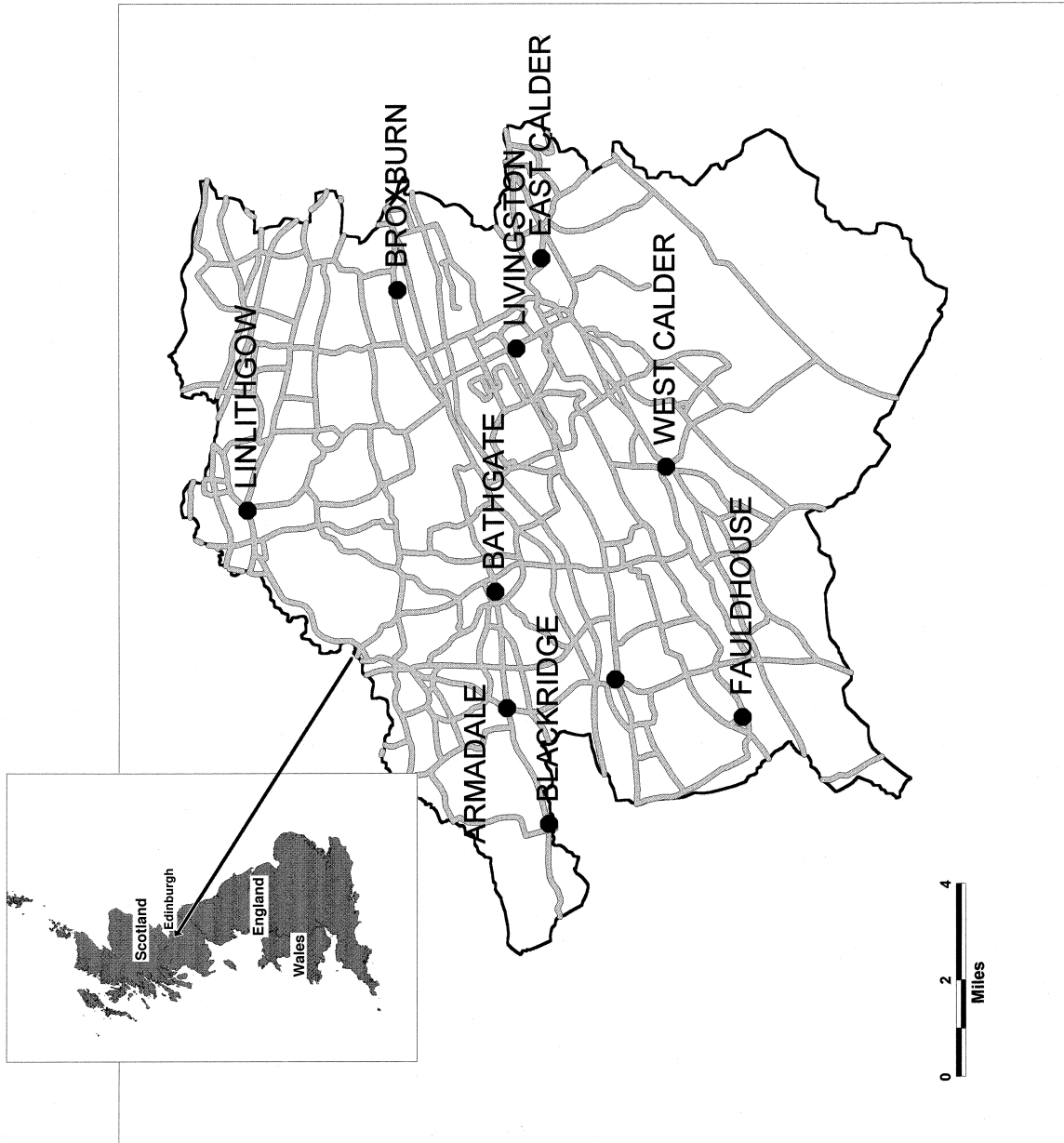


Figure 1. West Lothian, Scotland with main population centres and road network (UK inset).

In order to gain an insight into patients' decision-making with regard to choice of practice, and in order to illustrate the display functions possible in a GIS, spider graphs (ie straight lines connecting peripheral points to a central point) were drawn for four randomly selected practices using the geo-referenced postcodes for the practices (centrally) and the patients home addresses (peripherally). Thiessen polygons² were drawn for each of the practices in West Lothian in order to determine whether or not patients attended their closest practice. Because the point coverage boundaries of the polygon did not match the boundaries of West Lothian, the calculated boundaries for peripheral polygons were edited manually, and clipped to the boundaries of West Lothian.

Results

During the one week study period 8005 patients were seen at routine consulting sessions in the 18 participating practices. Questionnaires were completed in respect of 5,283 (66%) of these — postcodes that could be geo-referenced were obtained from 3,931 (74%) of these patients compared with 4,255 of the 5,685 (75%) patients recorded

on the hospital computer as attending accident and emergency in the eight week study period.

Accident and emergency utilization

A distance decay effect was evident in the pattern of patients selfreferral for Accident and Emergency care (*Figure 2*) — that is, use of the service decreases with the patients' distance from the hospital. *Figure 3* demonstrates a similar effect using network distances. Comparison of equivalent distance buffers between the two figures reveals the distortion of the buffer which take place when network distance is used rather than straight-line distance.

Figure 4 highlights a four-fold variation between the 20 postcode sectors in West Lothian in self referral rates for accident and emergency care over the eight week study period. Such a variation begs an explanation, and we have been able to investigate the potential socio-economic influences on these discrepancies by mapping car and home ownership information (*Figures 5 and 6*) and Jarman's UPA score (*Figure 7*) for these postcode sectors. One postcode sector immediately west of the AED sector had an unusually low rate of self referral for AED care despite it's geographical proximity. Inspection of *Figures 5–7*

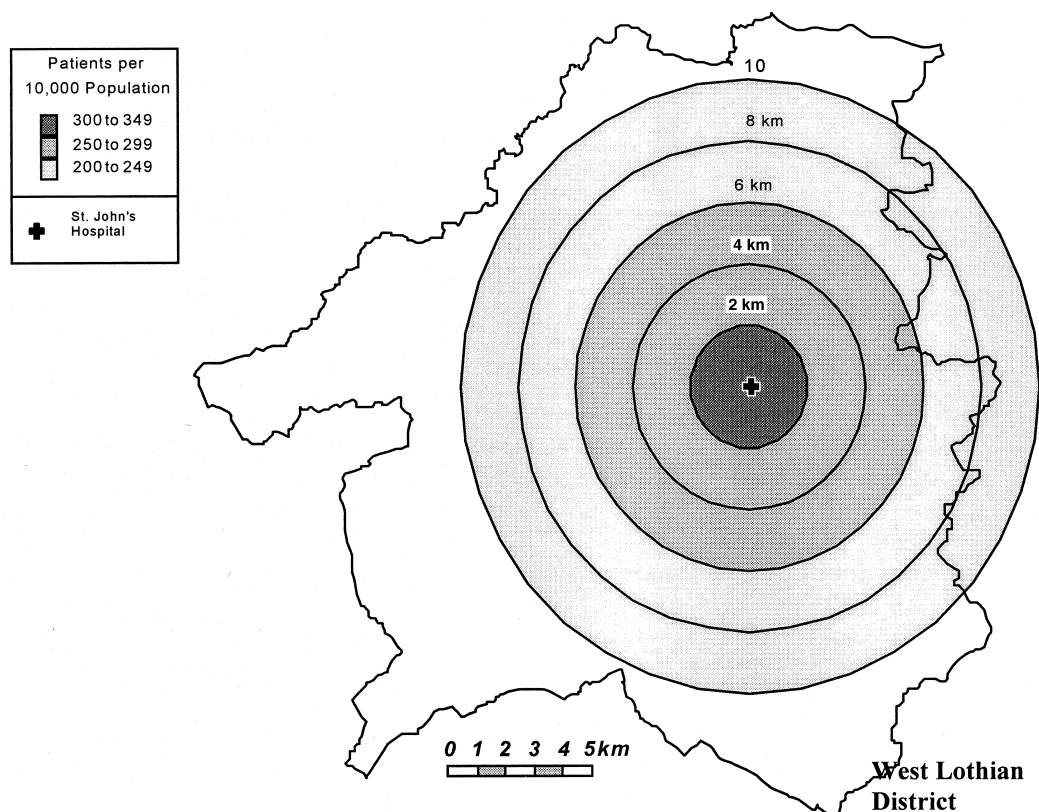


Figure 2. Accident and emergency (self referral) as a percentage of the 1991 census population. Two kilometer distance bands centered on St. John's Hospital, Livingston, West Lothian, Scotland.

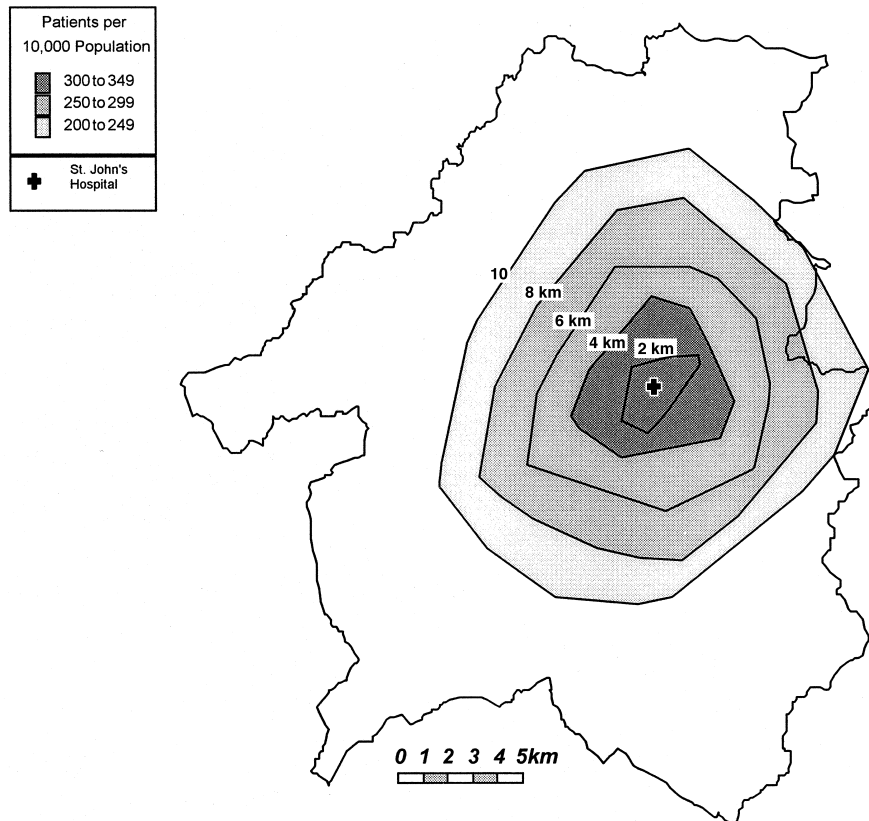


Figure 3. Accident and emergency patients as a percentage of the 1991 census population within two kilometer network distance bands centered on St. John's Hospital, West Lothian, Scotland.

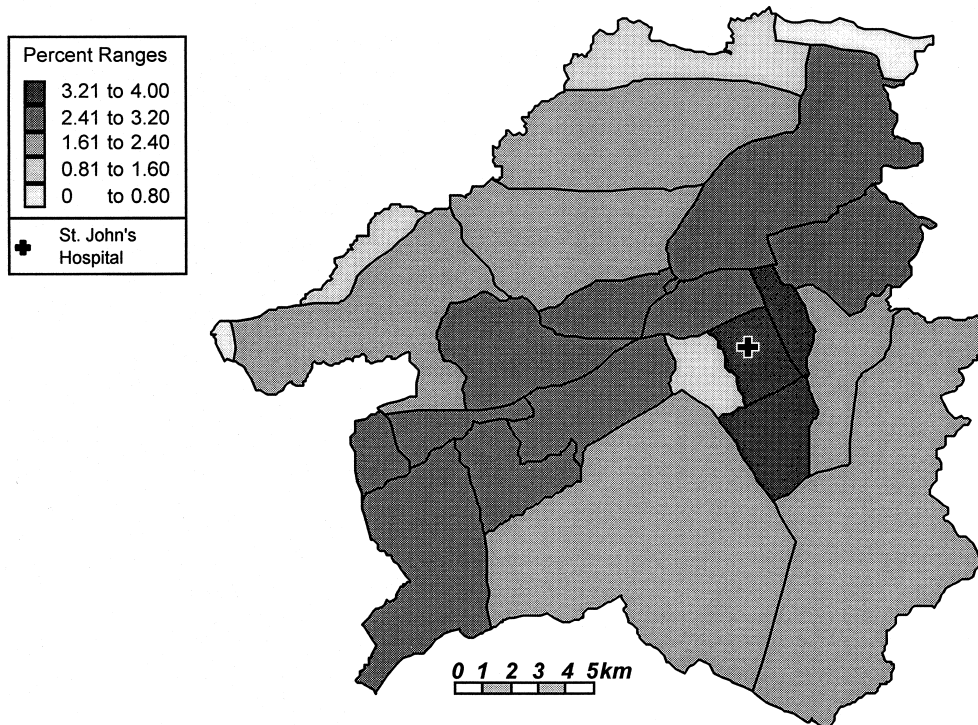


Figure 4. Accident and emergency patients as a percentage of the total 1991 census population for 20 postal sectors in West Lothian, Scotland.

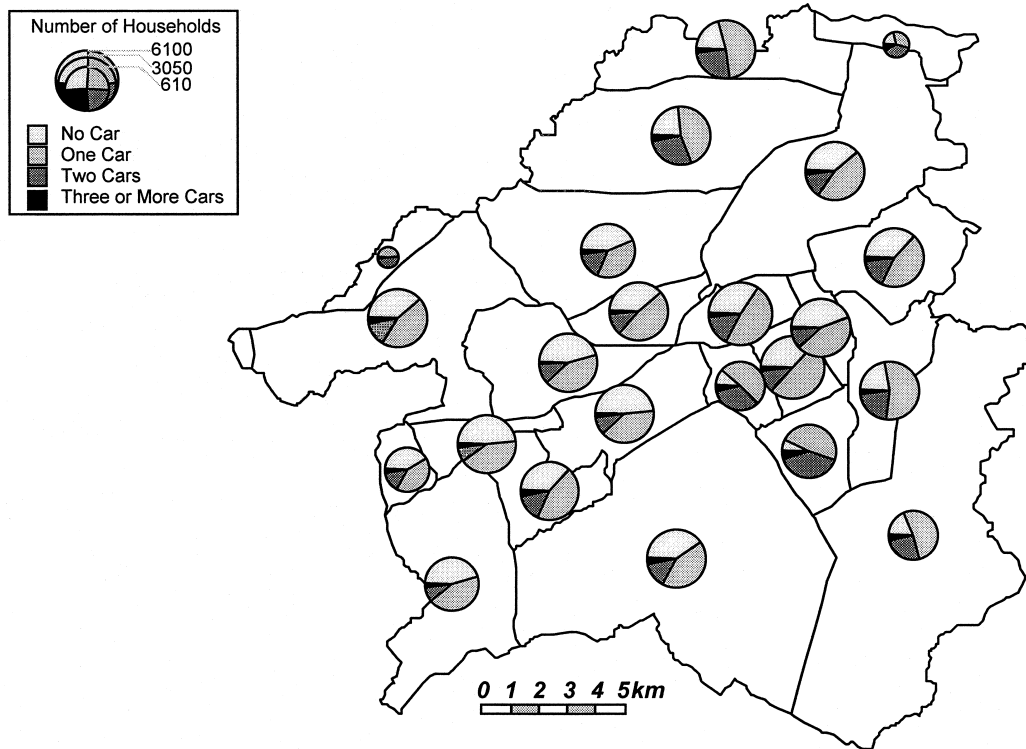


Figure 5. Household car ownership by postal sector. Twenty postal sectors in West Lothian, Scotland. Data based on 1991 census information.

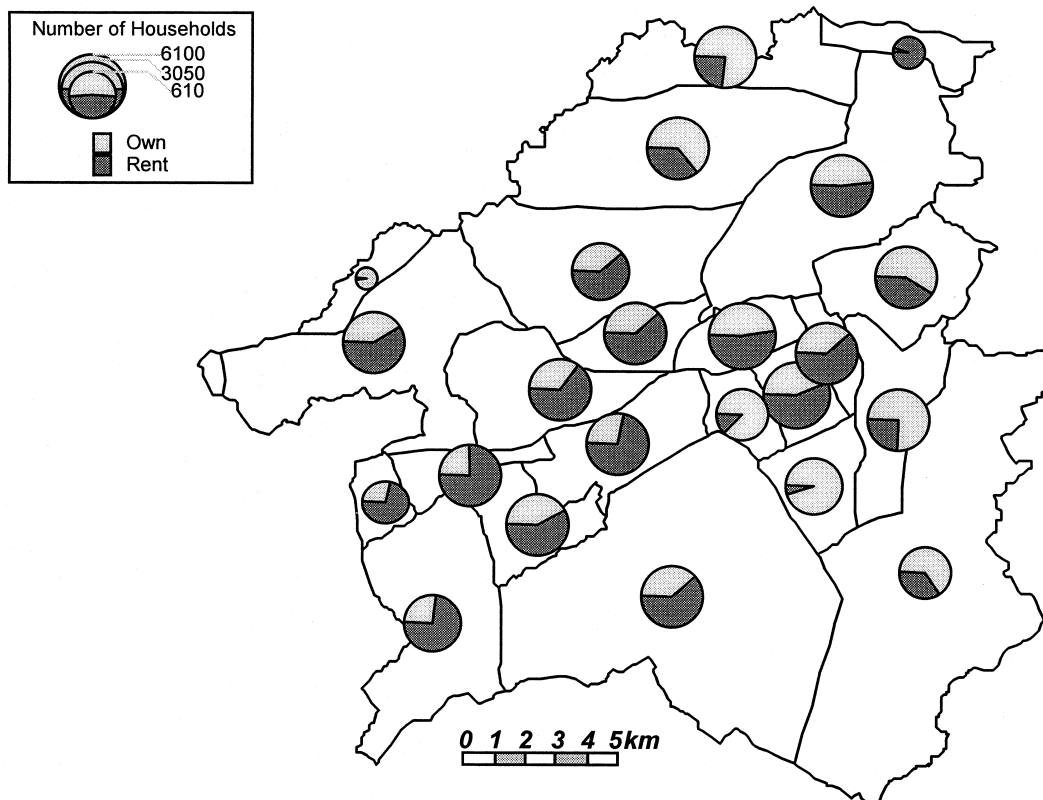


Figure 6. Home ownership by postal sector. Data based on 1991 census information for twenty postal sectors in West Lothian, Scotland.

demonstrate that this is a sector with higher than average rates of car and home ownership, and with a low UPA score when compared with the other postcode sectors in West Lothian. It would appear that sectors with lower Accident and Emergency usage may be those with lower socio-economic deprivation as evidenced by lower UPA scores and increased car/home ownership.

Utilization of general practitioner services

The distribution of the home postcodes of patients attending four practices in West Lothian is demonstrated in *Figure 8*. It can be seen that whilst the majority of patients choose medical practices near their home address, many patients do not elect to receive medical services from the practice which is geographically closest to their home address. The average straight line distance travelled to general practitioner surgeries was 1.23 km. However, through the use of Thiessen polygons, and point in polygon operations, it was calculated that the average distance travelled would have been 0.94 km if all patients had chosen their closest surgery. One consideration in the decision to seek care from a practice which is

not geographically closest to the patient's home address may be the patients perceptions of the time spent travelling to their general practitioner. This possibility was investigated by mapping perceived travel time contours based on questionnaire responses from patients using private transport to attend one practice. This procedure highlighted a pocket of difficulty for a group of patients reporting a travel time of 30–45 min despite being close to the surgery in crow-fly terms; the opposite effect was also evident — some patients further away from the surgery reporting short travel times. Comparison was also made between perceived distance (as reported in the questionnaire survey) and actual network distances travelled to each of four participating practices. Although patients perceptions are a subjective measure and might be influenced by many factors, the patterns may provide an indication of patients' general impression of ease of access. *Figure 9* illustrates that patients attending surgery 2 appear to believe they live closer to the practice than they do, whereas a significant number of patients from Practice 18 overestimate their distance from the practice.

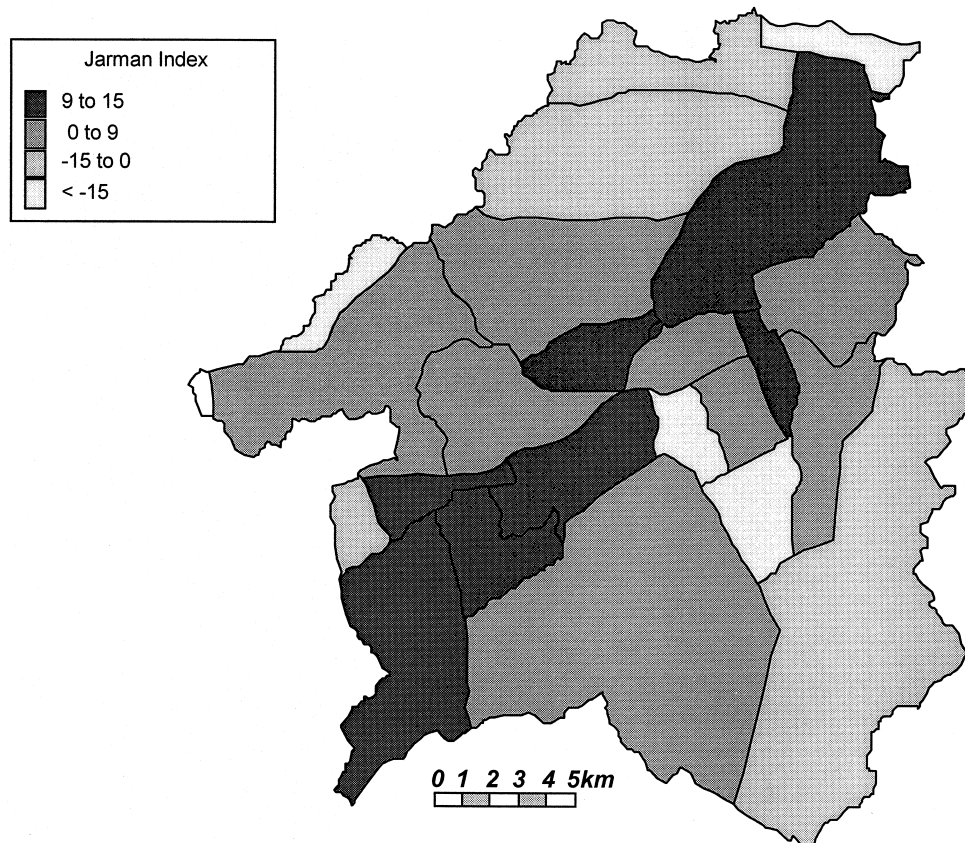


Figure 7. 1991 Jarman indices by postal sector in West Lothian, Scotland. Twenty postal sectors with data obtained from 1991 census information.

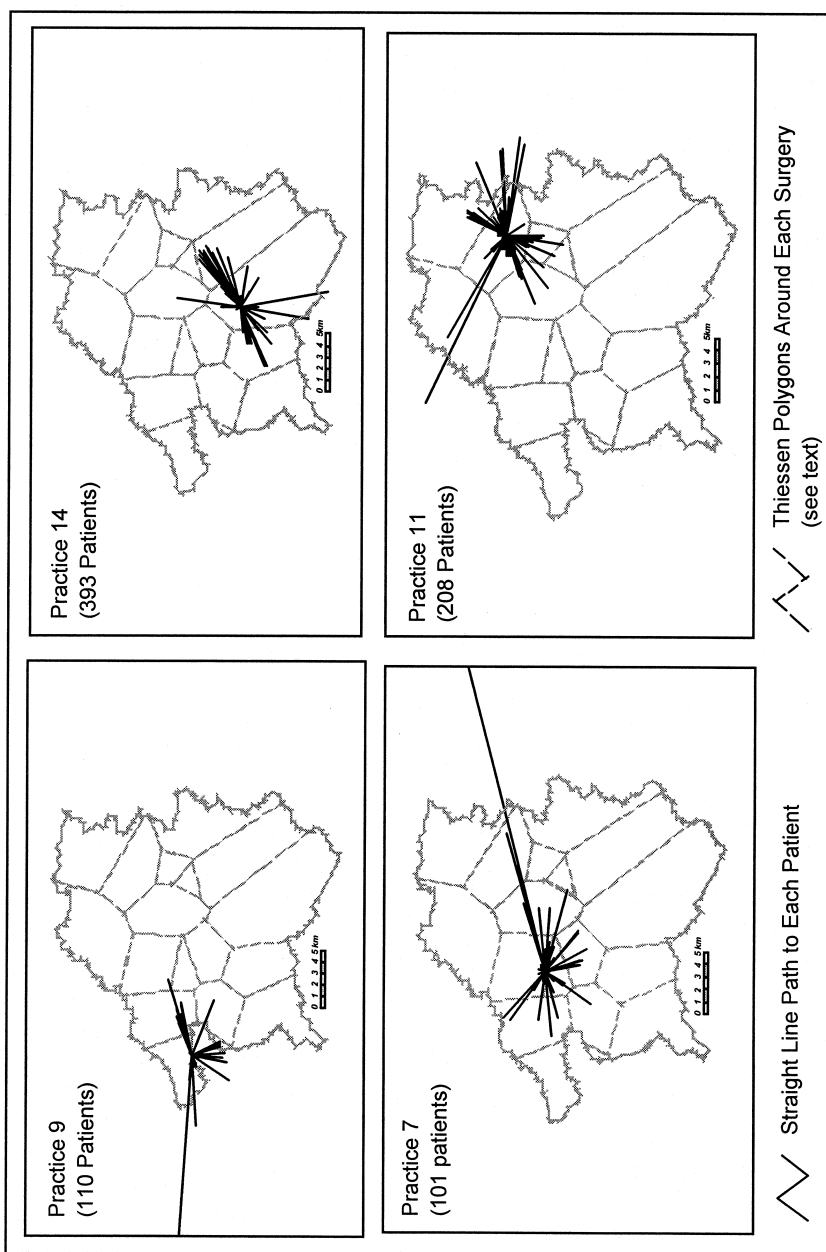


Figure 8. Patient locations (stated home postcodes in questionnaire survey) for four participating general practitioner surgeries in West Lothian, Scotland. () Number of respondents in practice.

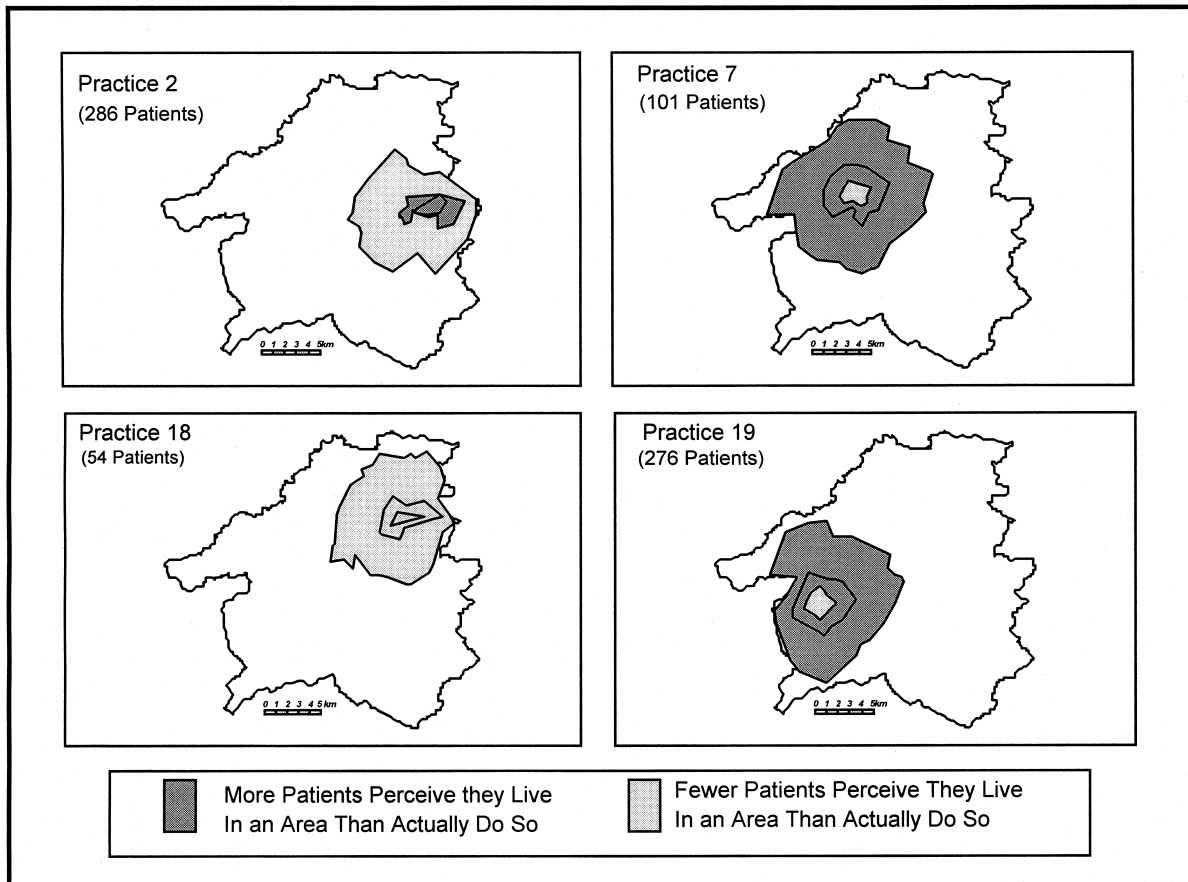


Figure 9. Actual vs perceived distance to four randomly selected study practices by network distance bands. Plots centered on practice location.

Discussion

Recent years have seen a burgeoning interest in the geographical and spatial aspects of the analysis of health care delivery. GIS technology has been identified as a potentially valuable adjunct in epidemiology (Lovett, 1992) and in the spatial analysis of health care utilization. This study examines the potential role of GIS technology within the context of general practice, and at the boundary between primary and secondary care — the Accident and Emergency department. We have used the querying and display functions of ARC/INFO, and the analysis of straight line, network, and perceived travel distances to service centres to highlight issues relating to the accessibility of primary care medical services. We have confirmed distance from the accident and emergency department to be a determinant of a patient's decision to self refer there for medical care, and have highlighted the effect that distance per se has in the decision made by patients regarding which practice they will receive care

from. Contour mapping of perceived travel time has highlighted difficulties for some patients in their perception of the accessibility of local medical services. Integration of information obtained from patient surveys and electronic data capture of hospital records with census information has permitted investigation of some of the socio-economic variables potentially influencing the use of these services.

Geo-referenced information was derived from postcode information obtained from several sources. The questionnaire survey yielded an adequate overall response rate. Information regarding hospital AED attendance was obtained from the hospital's computerized record of AED attendance, and was assumed (in view of the far reaching administrative and medico-legal implications) to be a complete record of all AED attendances during the study period. Postcode matching, and consequent geo-referencing of information was achieved for 75% of the postcodes provided. It was not possible to say how much of the remainder was a result of inadequate post-

code information provided at source by patients, inadequate processing by hospital staff, or limitations of the POSTZON file to match postcodes.

Service utilization

Service utilization has been described previously as 'revealed accessibility' (Joseph and Phillips, 1984). In this study we have highlighted a distance decay effect in the self referral patterns of patients to one accident and emergency department. Self referral was chosen as the unit of investigation since this is determined by the patients themselves, and so is not subject to medical determinants such as the notoriously variable referral patterns amongst general practitioners (Coulter *et al.*, 1992). Incorporation of network distance information resulted in a change in the shape of distance buffers mapped centering around the accident and emergency department although a distance decay effect was still clearly evident.

A five fold variation in self referral to Accident and Emergency was evident amongst the population of the 20 postcode sectors in West Lothian. Mapping of census variables potentially contributing to this variation revealed the possible contribution of socio-economic factors such as those employed in the Jarman UPA score. In this situation GIS proved a useful tool for highlighting potential associations and identifying areas in need of further research and analysis.

The definition of optimal catchment ('trading') areas around practices on the basis of distances between practices, and the mapping of home location of patients attending the practice during the one week survey period revealed the crow-fly distances travelled from home to practice and the dispersion of these patients around the practice. The numbers of patients a general practitioner can adequately provide quality care for has been the subject of recent research (Butler and Calnan, 1987; Calnan and Butler, 1988; Groenewegen *et al.*, 1992; Campbell, 1996), but this study highlights geographical dispersion of patients as a further variable which might contribute to the quality-of-care equation. Further work has recently been undertaken examining the relationship between the dispersion of patients around practices and the quality of care provided by those practices (Jenkins and Campbell, 1996).

The perceived accessibility of general practice was investigated by comparing reported travel times to the practice with estimates of network distances travelled. The GIS/Mapping system highlighted a pocket of difficulty for one practice — even when the method of travel had been controlled for. Mapping of such information results in a striking visual demonstration of an important observation.

Is GIS technology a useful investigative tool?

From the case study outlined above, it is concluded that GIS allows for a wide range of relevant analyses to be conducted — many of these would have been extremely time consuming and/or impossible to complete using traditional methods of analysis. Moreover, the results obtained may be used to augment those from more traditional studies and thus provide decision makers with greater amounts of relevant information from which to make informed decisions. From the first epidemiological studies to the more recent analyses of patient health needs and behavioral patterns, it is possible to trace an increasing interest in and use of GIS in health related studies. To date however, it appears that little time or money has been invested in this potentially useful technology by health care planners in the United Kingdom. It is to be hoped that organizational structures and practices will begin to change to make room for this new approach.

Summary

In order to ensure equality of access to medical services, and to ensure that resources are used in the most cost effective manner, it is increasingly important to understand the influences affecting the utilization of health care services. This study has successfully employed GIS technology to examine the utilization of general practitioner and Accident and Emergency services in one geographical area. Utilizing the extensive facilities of ARC/INFO in conjunction with database and census information permitted a detailed analysis of the effect of distance on the use of accident and emergency services, and helped examine some of the variables influencing a population's use of Accident and Emergency services. The technology was successfully employed to examine perceived and predicted accessibility of general practices and the spatial distribution of patients using general practitioner services in a one week study period. Such detailed analysis of the spatial elements contributing to the use of these resources could not have been carried out using conventional analyses. It is concluded that GIS technology is an important addition to conventional methods of analysis for defining the use of health services by the population.

Acknowledgements

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Notes

¹“Buffer”: “an area of specified width drawn around one or more map elements” (Aronoff, 1991). “Convex Hull”: an area created by joining the outermost points related to a particular criteria — in this case the point on each road segment which represents a predefined distance from a central point.

²Polygons defining an area where all locations in the polygon are nearer to the defining point (in this case the practice) than any other.

References

- Aronoff, S. (1991) *Geographic Information Systems: A Management Perspective*, WDL Publications, Ottawa.
- Bloemberg, B. P. M. and Doornbass, G. Harts, J. (Eds.) (1992) *Regional Health Profiles: A Description of the Health Status in 64 Public Health Service Districts in the Netherlands*, pp. 1392–1397.
- Butler, J. and Calnan, M. (1987) *Too many patients? A study of the economy of time and standards of care in general practice*, Avebury, Aldershot, Hants.
- Calnan, M. and Butler, J. R. (1988) The economy of time in general practice: an assessment of the influence of list size. *Social Science and Medicine* **26**, 435–441.
- Campbell, J. L. (1994) General practitioner appointment systems, patient satisfaction, and use of accident and emergency services: a study in one geographical area. *Family Practice* **11**, 438–445.
- Campbell, J. L. (1996) The reported availability of general practitioners and the influence of practice list size. *Br. J. Gen. Prac.* **46**, 465–468.
- Clarke, J. E. R. (1992) The potential application of a GIS for planning and monitoring service provision for people with dementia in Lothian Region. (Unpublished work).
- Great Britain Post Office Postzon file. ESRC Data Archive, Colchester (1988).
- Coulter, A., Roland, M. O. and Wilkin, D. (1992) GP referral to hospital: A guide for Family Health Service Authorities, University of Manchester Center for Primary Care Research, Manchester.
- Curtis, S. E. (1989) The development of geographical information systems for locality planning in health care. *Area* **21**, 391–399.
- Dowie, P. J., Koval, S. J., Burnhill, P. M. and Healy, R. G. (1995) GIS and community health care: a study of geriatric services provision.
- Dunn, C. (1992) *GIS and Epidemiology. Education, Training and Research*. Publ. 5, Association of Geographic Information, London.
- Fiedler, J. L. (1981) A review of the literature on access and utilization of medical care with special emphasis on rural primary care. *Social Science and Medicine* **15**, 129–142.
- Glass, D. (1991) A world health organization pilot study involving environment, public health and GIS. *Mapping Awareness and GIS in Europe* **6**, 36–40.
- Groenewegen, P. P., Hutten, J. B. and van der Velden, K. (1992) List size, composition of practice and general practitioners’ workload in The Netherlands. *Social Science and Medicine* **34**, 263–270.
- Hayes, S. M., Kearns, R. A. and Moran, W. (1990) Spatial patterns of attendance at general practitioner services. *Social Science and Medicine* **31**, 773–781.
- Ingram, D. R., Clarke, D. R. and Murdie, R. A. (1978) Distance and the decision to visit an accident and emergency department. *Social Science and Medicine* **12**, 55–62.
- Jarman, B. (1983) Identification of underprivileged areas. *BMJ* **286**, 1705–1709.
- Jenkins, C. and Campbell, J. L. (1996) Catchment areas in general practice and their relation to size and quality of practice and deprivation: a descriptive study in one London borough. *BMJ* **313**, 1189–1192.
- Joseph, A. E. and Bantock, P. R. (1982) Measuring potential physical accessibility to general practitioners in rural areas: a method and case study. *Social Science and Medicine* **16**, 85–90.
- Joseph, A. E. and Phillips, D. R. (1984) *Accessibility and Utilization: Geographical Perspectives on Health Care Delivery*, Harper and Row, New York.
- Joseph, A. E. and Poyner, A. (1982) Interpreting patterns of public service utilization in rural areas. *Economic Geographer* **58**, 262–273.
- Kivell, P. T. and Mason, K. T. (1992) Monitoring the healthy city: GIS and health care management in North Staffordshire.
- Knox, P. L. (1978) The intraurban ecology of primary medical care: patterns of accessibility and their policy implications. *Environment and Planning (A)* **10**, 415–435.
- Knox, P. L. (1979) The accessibility of primary care to urban patients: a geographical analysis. *Br. J. Gen. Prac.* **29**, 160–168.
- Lovett, A. A. (1992) *Geographical Information 1992/3: The Yearbook of the Association for Geographic Information*. Taylor and Francis, London.
- Matthews, S. A. (1991) *Epidemiology using a GIS: the need for caution*. (Unpublished work).
- Morgan, K. (1990) *A Geographical Information System in Health Service Planning in Avon*. Bristol.
- Nicol, J. (1991) Geographic information systems within the National Health Service: the scope for implementation. *Planning Outlook* **34**, 37–42.
- Phillips, D. R. (1979) Spatial variations in attendance at general practitioner services. *Social Science and Medicine* **13**, 169–181.
- Sackett, D. L., Haynes, R. B., Guyatt, G. H. and Tugwell, P. (1991) *Clinical Epidemiology. A Basic Science for Clinical Medicine*, 2nd edn. Little, Brown and Co, London.